British Journal of Applied Science & Technology
19(3): 1-7, 2017; Article no.BJAST.31141
ISSN: 2231-0843, NLM ID: 101664541

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Utilization of Plastic Wastes in Asphalt Design for Road Construction

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Authors' contributions

This work was carried out in collaboration between all authors. Author MBD designed the study, wrote the protocol, proof read the drafts and managed the literature searches. Authors SDM and JSO managed the analyses of the study and wrote the first draft. Author SDM wrote the final draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2017/31141
Editor(s):
(1) Aleksey Aleksandrovich Hlopitskiy, Department of Technology inorganic substances, Ukrainian State University of Chemical Technology, Ukraine.
Reviewers:
(1) Nur Izzi Md. Yusoff, Universiti Kebangsaan Malaysia, Malaysia.
(2) Halil Görgün, Dicle University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/18195

Original Research Article

Received 22nd December 2016
Accepted 13th January 2017
Published 15th March 2017

ABSTRACT

The use of synthetic polymers (Plastics) has become part of our everyday life since their introduction over 100 years ago. Every vital section of the economy ranging from clothing, agriculture, packaging, automobile, medicine, electrical and electronics have been virtually revolutionized by application of plastics. The challenge of the disposal of these plastics after use is what this study seeks to address in part. Low density polyethylene (LDPE) and polyethylene terephthalate (PET) plastic wastes were blended with bitumen as binder for road construction as an effective and valuable means of disposing these wastes, employing marshall hot-mix design. 15% and 30% w/w LDPE and PET wastes of total binder required for the asphalt design were incorporated at 6% optimum binder content. The polymer modified asphalts (PMA) were tested for marshall stability and flow. At 15% w/w LDPE, the stability and flow values are 819 kg and 3.6 mm, respectively, while at 30% w/w LDPE, the stability and flow values are 643 kg and 4.1 mm, respectively. Similarly, at 15% w/w PET, the stability and flow values are 737 kg and 3.3 mm, respectively, while at 30% w/w PET, the stability and flow values are 707 kg and 3.5 mm, respectively. These results are in agreement with the "general specification for roads and bridges, vol. II (1997)" of the federal government of Nigeria, which specifies a minimum of 350 kg and

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2-4 mm for stability and flow, respectively. However, the 15% LDPE and PET plastic wastes incorporation gives better results than that of the 30% incorporation.

Keywords: Plastic wastes; Marshal stability; pollution; asphalt; binder.

1. INTRODUCTION

Municipal solid waste management has become a threat to the environment and the greatest problem facing many urban and semi-urban areas in Nigeria and worldwide. An average Nigerian is estimated to generate about 0.49kg of solid wastes per day with household and commercial centers contributing about 90% of the total urban waste burden [1]. In Nigeria, plastics constitute between 40% and 60% of the volume of solid wastes. It was estimated that, Kano metropolis generated about 3085 tonnes of solid wastes per day and more than half of these solid wastes are plastics [2]. The menace of plastic wastes in Nigeria can be attributed to a number of root causes: first and foremost is the fact that, no one is paying for the adverse impact that plastic wastes are causing to the environment; secondly, proper collection and disposal of the plastic wastes are not factored in the product cost of the materials, as a result, plastic packages have become overly so cheap that they are given away "for free" at supermarkets and kiosks [3].

As a result of the vast applications (consumption) of plastics especially LDPE and PET, the pressing question that needs to be addressed is, "*what happens to all the plastics after use?"* In 2012, Nigeria was faced with a serious problem of flood, which claimed many lives and properties. Many see plastic as the number one culprit in the 2012 flood.

According to the American Plastic Council (APC), only about 8% of plastics consumed are recycled. Most end up in land filling and incinerators which does not solve the problem of pollution. Therefore, the only way of addressing the problem of disposal of post-industrial and post-consumer plastic wastes is through recycling [4]. For the past two decades, research has been conducted on the use of polymer such as PET and PE wastes for plastic modified asphalt (PMA) mixture. This can successfully improve the performance of asphalt pavement at low, intermediate and high temperature by increasing mixture resistance to fatigue, cracking, thermal cracking and permanent deformation [5].

In a report based on experiment, asphalt mixture with waste PE modifier up to 10% and waste PVC modifier of 7% can be used for flexible pavement construction in warmer region from stand point of stability, stiffness and voids characteristics. The results obtained indicate that, the unit weight and stability of the compacted specimen shows an appreciable increasing behavior initially with an increase of PE and PVC content in bitumen. After reaching to an optimum content of PE and PVC, it shows a declining behavior with the increment of PE and PVC on binder [6].

This study seeks to incorporate up to 30% w/w LDPE and PET plastic wastes of total binder required for the asphalt design into bitumen for road pavement. This will help to secure an environment friendly way of plastic wastes disposal, improve soil compost for agriculture, reduce the demand of bitumen, reduce the cost of road construction and create job opportunities.

2. MATERIALS AND METHODS

2.1 Sample Collection

The Polyethylene Terephthalate (PET) and Polyethylene (PE) wastes were collected from a waste dump-site in Mista Ali (Zaria road) Bassa LGA, Plateau State, Nigeria. A 60/70 bitumen sample and aggregates of 14 mm, 10 mm and stone dust were graciously obtained from P.W Nigeria Limited, Vom Quarry in Plateau State, Nigeria.

2.2 Sample Treatment

The plastic waste types were washed in a warm water containing detergent and bleach to remove dirt and disinfect them, after which they were sundried and sorted out according to the Society of the Plastics Industry (SPI) resin identification code. This was followed by shredding into sizes between 2 and 4 mm with a pair of shear (scissors).

2.3 Aggregate Testing

The aggregates were analyzed according to the British Standard (BS 812) for testing aggregates to employ a job-mix and to ensure the aggregates were of standard and sound quality for use in the asphalt design.

2.3.1 Sieve analysis of aggregates

The practical combination for the wearing-coarse design is to weigh 1200 g. A representative sample of each of the aggregate type was riffled with a riffle box. 75% by weight of the total-mix (1200 g) was assigned for stone dust, 5% for 10 mm aggregate and 20% for 14 mm aggregate. They were mixed and sieved in a vertically arranged sieves in order of descending mesh seizes; 20 mm, 14 mm, 10 mm, 6.3 mm, 1.18 mm, 600 µm, 150 µm, 75 µm and the base. The weight retained at each sieve was noted and the percentage retained calculated as thus:

$$\%\,retained = \frac{weightretained}{1200} X\,100 \quad (1)$$

2.3.2 Determination of specific gravity of aggregates

First, an empty Picnometer was weighed and the weight labeled A. The aggregate (14 mm) were added to the picnometer and weighed (recorded as B). The picnometer containing the aggregate was then filled with water to the brim and weighed (C). Finally, the picnometer was filled to the brim with water only and weighed (D). The specific gravity was calculated using the formula below

$$\text{specific gravity (SG)} = \frac{(\mathrm{B}-\mathrm{A})}{(\mathrm{D}-\mathrm{A})-(\mathrm{C}-\mathrm{B})}(\mathrm{mg/m}^3) \quad (2)$$

The above procedure was repeated for 10 mm aggregate and the stone dust.

The specific gravity of the mixed aggregate (SGMA) was calculated using the formula below:

$$SGMA = \frac{100}{\left(20/_{SG\,of\,14mm}\right)+\left(5/_{SG\,of\,10mm}\right)+\left(75/_{SG\,of\,stonedust}\right)} \quad (3)$$

2.3.3 Determination of elongation index of aggregates

The Aggregates that passed through sieve 14 mm and were retained in 10 mm during the sieve analysis were weighed and passed one after another through the "14 to 10 mm" space on the elongation index test instrument. The aggregates retained were weighed and the percentage retained calculated.

$$\%\,retained = \frac{weight\ retained}{total\ weight\ of\ sample\ on\ 10\ mm\ sieve} X\,100 \quad (4)$$

2.3.4 Determination of flakiness index of aggregates

The Aggregates that passed through sieve 14 mm and were retained in 10 mm during sieve analysis were weighed and passed one after another through the "14 to 10 mm" space on the flakiness index test instrument. The aggregates which passed successfully were weighed and the percentage passed was calculated

$$\%\,passed = \frac{weight\ passed}{total\ weight\ of\ sample\ on\ 10\ mm\ sieve} X\,100 \quad (5)$$

2.3.5 Determination of impact value of aggregates

The sample of 14 mm aggregates were collected and riffled in the riffle box. The mould of the impact value machine was filled with the riffled sample and then compacted using tamping rod with 15 strokes. The sample in the mould was then rammed with 15 blows. Finally, the rammed sample was weighed and sieved with a 2.36 mm BS sieve and the percentage passed calculated

$$\%\,passed = \frac{weight\ passed}{total\ weight\ of\ sample} \mathrm{X}\,100 \quad (6)$$

2.4 Asphalt Hot Mix Design with Polyethylene (PE) and Polyethylene Terephthalate (PET) Plastic Wastes

The asphaltic design of 6% optimum binder content was done for three different percentages of PET and PE wastes in the total mix. The design was done for

1. Asphalt free of plastic wastes.
2. 85% bitumen and 15% plastic wastes.
3. 70% bitumen and 30% plastic wastes.

1. Job Mix for 100% Bitumen with 0% Plastic Wastes

a) $$6\%\,bitumen = \frac{6}{100} X\,1200 = 72gms \quad (7)$$

b) $$94\%\,aggregates\,combination = \frac{94}{100} X\,1200 = 1128gms \quad (8)$$

Job mix formula for each aggregates type

14 mm aggregates = 20% of 1128 = 226 gms
10 mm aggregates = 5% of 1128 = 56 gms
Stone dust = 75% of 1128 = 846 gms
Total = 1128

2. **Job Mix for 85% Bitumen with 15% Plastic Wastes**

   Plastic waste = 15% by weight of total binder = $\frac{15}{100} X\ 72 = 11g$ (9)

   Bitumen = 85% by weight of total binder = $\frac{85}{100} X\ 72 = 61g$ (10)

   The Job mix of each aggregate type is maintained.

3. **Job-Mix for 70% Bitumen with 30% Plastic Wastes**

   Plastic waste = 30% by weight of total binder = $\frac{30}{100} X\ 72g = 22g$ (11)

   Bitumen = 70% by weight of total binder = $\frac{70}{100} X\ 72g = 50g$ (12)

   Note that the Job-mix of each aggregate type is maintained.

2.5 Design Procedure

The design was done in duplicate for each job-mix. First, the aggregates of different sizes were collected and sun dried to remove moisture. The different aggregate sizes were heated on a sample tray to a temperature of 150°C in the ovum. The plastic wastes were melted separately (PET wastes were melted at 250°C while LDPE wastes was melted at 110°C) and the bitumen also, was heated to 150°C.

The aggregates and binder (bitumen or bitumen and plastic wastes, as the case may be) were mixed according to the job-mix, for the three different cases. The mixture was then properly mixed on a source of heat with temperature maintained at 150°C. The hot mixture was poured into a warm standard Marshall Compaction mould and compacted with 75 blows given at both sides (150 blows altogether).

On cooling, a protruding jack was used to remove the compacted asphalt from the mould. The asphalt was then left to set for at least 24 hours, after which it was tested for Marshall Stability and flow.

3. RESULTS AND DISCUSSION

3.1 Results of Sieve Analysis for Wearing Course Practical Combination Mix

The result on Table 1 below shows the size distribution of the mixed aggregates (practical combination) which shows the quality of the aggregate and also serve as a guide to obtain the percentage job-mix of the aggregate types. The percentage passing fall within the specification (BS 812) which is also in line with the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of Nigeria, therefore, 20%, 5% and 75% by weight were chosen for 14 mm,10 mm aggregates and the dust, respectively, for the job-mix.

Table 1. Results of sieve analysis for wearing course practical combination mix

Sieve size	Weight retained	% retained	% passed	BS 812 specification
20 mm			100	100
14 mm	21	1.8	98.2	85 – 100
10 mm	177	14.8	83.4	75 – 92
6.3 mm	128	10.7	72.7	65 – 82
2.36 mm	215	17.9	54.8	50 – 65
1.18 mm	133	11.1	43.7	36 – 51
600 µm	110	9.2	34.5	26 – 40
300 µm	102	8.5	26.0	18 – 30
150 µm	138	11.5	14.5	13 – 24
75 µm	77	6.4	8.1	7 – 14
Passing 75 µm	99	8.2		
Total	1200			

3.2 Results of Specific Gravity for Mixed Aggregates

Specific gravity is a measure of a material's density (mass per unit volume) as compared to the density of water at 23°C. Correct and accurate material specific gravity determinations are vital to proper mix design. An incorrect specific gravity value will result in incorrect calculated volumes and ultimately result in an incorrect mix design. It can also indicate possible material contamination. Also, specific gravity differences can be used to indicate a possible material change. A change in aggregate mineral or physical properties can result in a change in specific gravity. The specific gravity of the mixed aggregates determined was found to be 2.63, which meet the specification of 2.5 to 3.0 as given in BS 812. Therefore, the aggregates are fit to be used for the design.

3.3 Results of Elongation Index and Flakiness Index Tests

The elongation index is a characterization used in the super-pave specification to identify aggregates that may have a tendency to impede compaction. The elongation index value must be less than 30% according to the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of Nigeria and also according to BS812. A value of 22.9% was obtained for the elongation index which fall within the specification. Therefore, the aggregate is suitable for use in asphalt design.

Flakiness index shows the percentage of particles in a coarse aggregate that have a thickness (smallest dimension) of less than one-half of the nominal size. This too, must have a value of less than 30%, to be seen fit for use in road pavement as given on the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of Nigeria and also on BS812. The result of the flakiness index was found to be 22.2% which agrees with the standard, making it suitable for the design.

3.4 Result of Aggregate Impact Value (AIV) Test

Aggregate impact value shows the resistance of the aggregate to sudden shock or impact. The classification of aggregates based on AIV is as below:

<10% - Exceptionally strong
10-20% - Strong
20-30% - Satisfactory for road surfacing
>35% - Weak or not suitable for road surfacing

In essence, it must have a value less than 30% to be fit for use in road pavement. The value from the test was found to be 13.9% which implies that the toughness or resistance of the aggregate to impact is good, as it falls within specification given (BS 812) and on the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of Nigeria. The value of 13.39% indicates a strong aggregate.

3.5 Results of Voids in the Hot Mix Design

Table 2 shows results of voids analysis. The voids show the gap or opening in the mixed aggregates and total mix. The voids filled with binder (bitumen alone or bitumen with LDPE and PET wastes), are the inter-granular spaces occupied by the binder, whereas, voids in total mix are the percentage of space filled by air.

Table 2 indicates that, both the voids in total mix and the voids filled with aggregates are slightly out of the specification of the Federal Ministry of Works and Housing, Nigeria (1997). This can be attributed to the fact that, both the aggregates elongation and flakiness index values tilted towards their maximum, though within the specified ranges. This observation is same for the mix without the plastic wastes. However, these results agree with the work reported by Rahman et al. [6] and Mohammad and Lina [7] that, after reaching an optimum PE waste incorporation of 12% and 10% by weight of total binder, respectively, a declining behavior was observed. This however, suggests that, the life span of the plastic modified road in areas with high rainfall may be shorter than that in warmer areas.

3.6 Results of Marshall Stability and Flow Tests

The Marshall Stability and flow tests provide the performance prediction measure for the Marshall designed asphalt. The stability portion of the test measures the maximum load supported by the specimen at loading rate of 50.8 mm/min at standard temperature of 60°C. During the

Table 2. Results of voids in the hot mix design

S/No.	Samples	Void in total Mix (VTM), %	Voids in mineral aggregate (VMA), %	Voids filled with bitumen, %
1	100% Bitumen with 0% LDPE waste (100:0)	6.12	17.79	67.95
	100% Bitumen with 0% PET waste (100:0)	6.12	17.79	68.63
2	85% Bitumen with 15% LDPE (85:15)	7.35	18.87	63.86
	85% Bitumen with 15% PET waste (85:15)	7.35	18.87	63.86
3	70% Bitumen with 30% LDPE (70:30)	8.16	19.58	61.03
	70% Bitumen with 30% PET waste (70:30)	10.61	21.73	53.52
Specification as given by the Federal Ministry of Works and Housing, Nigeria (1997).		3 – 5%	16 - 19%	63 – 72%

Table 3. Results of Marshall stability and flow tests

S/No.	Samples	Marshall stability (kg)	Marshall flow (mm)
1	100% Bitumen with 0% LDPE waste (100:0)	1406	3.0
	100% Bitumen with 0% PET waste (100:0)	753	3.0
2	85% Bitumen with 15% LDPE (85:15)	819	3.6
	85% Bitumen with 15% PET waste (85:15)	737	3.3
3	70% Bitumen with 30% LDPE (70:30)	643	4.1
	70% Bitumen with 30% PET waste (70:30)	707	3.5
Specification as given by the Federal Ministry of Works and Housing, Nigeria (1997).		350 kg minimum	2-4 mm

loading, an attached dail gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is the deformation the Marshall Test specimen undergoes during the loading, up to the maximum load, 0.25 mm units. The results for the Marshall stability and flow as shown on Table 3 above, falls within the specification given on the "General Specification for Roads and Bridges, Vol. II" (1997), of the Federal Government of Nigeria.

4. CONCLUSION

The results obtained from the research indicate that, Low-Density Polyethylene (LDPE) and Polyethylene Terephthalate (PET) wastes can be used to contribute to the binder content in asphalt concrete for wearing course by the Marshall hot mix design method. That is, some percentage by weight of bitumen required for asphaltic concrete can be replaced with plastic wastes. The results also point to the fact that, LDPE and PET incorporation of 15% w/w of binder required, gives better result than that of the 30% w/w LDPE and PET wastes incorporation in terms of the Marshall stability, flow, and voids.

This is an environmental friendly way of disposing plastic wastes and will go a long way in addressing the menace of streets, towns, cities and ocean littering by plastic wastes. Soil fertility degradation as a result of the poor aeration and poor water penetration caused by these plastics can be checked, thereby improving compost for agriculture by separation of the plastics from other municipal solid wastes which are biodegradable.

Economic wise, the cost of road construction will be reduced by 11 g per every 72 g of bitumen required for asphalt concreting is saved. That is, about 15% of the cost of bitumen required for road pavement is cut down of which the cost of collecting, sorting, cleaning and shredding of the plastic wastes cannot account for this cost. Also, the service of people for the collection, sorting and cleaning of the wastes will be needed and as such, job opportunities will be created.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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   ISSN: 1546-9239.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/18195